

The role of biodiversity in integrated landscape approaches

Joli R Borah, Yves Laumonier, Eric RC Bayala, Houria Djoudi, Davison Gumbo, Kaala B Moombe, Elizabeth L Yuliani and Mathurin Zida

Introduction

Global biodiversity loss is a major challenge. Since 1970, the number of birds, mammals, reptiles and amphibians has dropped by more than half and over a quarter of all species (one million animal and plant species) are now threatened with extinction (Brondizio et al. 2019). The extinction rate is now 1000 times faster than in pre-industrialization times, suggesting the advent of a sixth mass extinction (Barnosky et al. 2011).

Biodiversity loss impacts ecosystem functioning, reduces the resilience of ecosystems and threatens human well-being (Johnson et al. 2017). For instance, a decline in soil and pollinator biodiversity has significantly reduced annual crop yields globally (Díaz et al. 2019). Similarly, loss of genetic diversity of cultivated crops, their wild relatives and domesticated breeds in agricultural systems makes them vulnerable to threats such as pests, pathogens and climate change (Díaz et al. 2019). Apart from species extinction, loss of overall abundance of multiple trophic groups can further exacerbate the provision of ecosystem functions (Newbold et al. 2015). These impacts can be potentially equivalent in magnitude to global drivers of environmental change such as drought, fire and global warming (Hooper et al. 2012).

VISIT...

LANZAROTE
Caliente.COM

The major drivers of biodiversity loss are land-use change, exploitation, pollution, invasion of alien and undesired native species, loss of pollinators and climate change (Díaz et al. 2019). These, in turn, are underpinned by a range of socioeconomic issues such as food and nutrition security (Montoya et al. 2020), livelihoods (Garibaldi et al. 2017), Indigenous rights (Witter and Satterfield 2019) and gender issues (Alvarez and Lovera 2016). This is particularly evident in the tropics, which harbor about two-thirds of the world's biodiversity (Giam 2017; Barlow et al. 2018) and is more pronounced in the subtropical dry forests and woodlands (Miles et al. 2006), where the anthropogenic pressures on the environment have escalated to an unprecedented level (Barlow et al. 2016; Swamy et al. 2018). A strictly conservation focus to address these challenges is limited in scope, as the well-being of the local communities, particularly those who are poor and vulnerable, is inextricably linked to the natural resources in these regions (Swamy et al. 2018; Schleicher et al. 2019). Thus, there is an urgent need for an integrated approach that better acknowledges and reconciles the deeply connected social, environmental, political and economic challenges in the tropics.

Biodiversity is an integral component of such integrated approaches as it contributes both directly and indirectly to food security and human well-being (Cramer et al. 2017). This chapter synthesizes the crucial roles of biodiversity and evaluates ways to conserve and monitor biodiversity within integrated landscape approaches.

3.1 Why is biodiversity important?

3.1.1 Biodiversity and food security

Biodiversity – that is, the variety of life across genes, species and functional traits – plays an integral role in ensuring food security, livelihoods and human well-being (Cardinale et al. 2012). Globally, 1.6 billion people rely on forests and biodiversity for food and livelihoods (Newton et al. 2020). Biodiversity is critical for safeguarding food and nutrition security, underpinning modern agriculture as well as the livelihoods of millions of forest-proximate communities (Richardson 2010; Sunderland 2011; Broegaard et al. 2017). Biodiversity contributes to food and livelihood security via a number of pathways, which we briefly summarize below.

Forest food

About one in six people rely on wild food such as wild vegetables and fruits, fungi, honey, edible insects and bushmeat across the world (Vinceti et al. 2013; Vira et al. 2015; Sardeshpande and Shackleton 2019). For instance, local communities use up to 800 species for wild food in Asia and Africa (Bharucha and Pretty 2010), while six million tons of bushmeat is extracted annually from the forests of Africa and South America (Overton et al. 2017; Baudron et al. 2019). Forest foods also provide a safety net to communities during food scarcity (Wunder et al. 2014), signaling the need to manage the interdependence between human needs and biodiversity conservation.

Nutrition and health

Biodiversity increases dietary diversity and nutritional quality, especially for local communities (Powell et al. 2015; Rasmussen et al. 2017). Wild foods are important sources of essential fatty acids, iron, zinc, calcium and vitamins (Glew et al. 1997). Deficiency in one or more of these micronutrients is most severe in the developing world, where production is highly dependent on pollinators (Chaplin-Kramer et al. 2014). Bushmeat and fish contribute to 20% of the protein requirement where other sources of protein are not available (Datta et al. 2008; Naro et al. 2015). In addition, up to 80% of the population in many developing countries depend on biodiversity for their primary health care (Herndon and Butler 2010). Biodiversity is often the basis for various forms of indigenous medicines that are critical for human survival, especially in developing countries (WHO 2002; Alves and Rosa 2007). Finally, biodiversity loss can also impact human health by increasing the emergence and transmission of infectious diseases (Keesing et al. 2010; Olivero et al. 2017).

3.2 Livelihood benefits from biodiversity

Plants and animals harvested from forests contribute significantly to the livelihood strategies of forest-dependent local communities (Delang 2006; Paumgarten and Shackleton 2009), especially in the case of women and the cash poorest (Pouliot and Treue 2013). The contribution of biodiversity to the economy of developing countries has been estimated to be USD 250 billion per annum (Agrawal et al. 2013). Meanwhile, environmental income was found to account for 28% of total household income in a comparative study across 24 developing countries (Angelsen et al. 2014). For instance, income generated from wild harvest in terms of fuelwood, bushmeat and wild foods was the second biggest contributor to local communities' total annual income in Ghana (Hansen et al. 2015). In Indonesia, 36% of the total income in indigenous households came from forest resources (Widianingsih et al. 2016). In southern Africa, some poor households derive close to 30% of their income from forests (Fisher 2004; Jumbe et al. 2008; Mulenga et al. 2012).

3.3 Adaptation and resilience benefits

Biodiversity plays a crucial role for resilience and adaptation of people. Ecosystem-based adaptation approaches provide cost-effective alternatives for buffering the impacts of climate change, while avoiding the many challenges of hard infrastructure (Jones et al. 2012). Hence, integrated approaches are crucial to capture context-specific, local connections and scale-related challenges between conserving ecosystem services and enhancing the adaptive capacity of people. Most of what is documented as losses and damages to human systems is inherently linked to permanent or temporary disturbances in the biodiversity of ecosystems due to climatic stressors, but studies of loss and damage from climate change tend to overlook the mediating role of biodiversity and ecosystems services to society (van der Geest et al. 2019). A systematic review

on the impact of climate change on most types of services found that the impact is predominantly negative (59% negative, 24% mixed, 13% positive, 4% neutral), but varied across services. However, very few studies integrated decision-making processes and users, and even fewer studies identified solutions that were robust to uncertainty (Runting et al. 2017). Integrative landscape approaches will help to incorporate this twofold nature of the linkages between ecosystem services and climate change.

3.4 Ecosystem services from biodiversity

Biodiversity maintains and enhances multiple ecosystem functions such as primary production, decomposition, nutrient cycling and trophic interactions that support a range of ecosystem services (Cardinale et al. 2012; Lefcheck et al. 2015; Soliveres et al. 2016). The different dimensions of biodiversity such as species richness and abundance, functional diversity (the range of functional traits in species) and phylogenetic diversity (diversity of evolutionary history in species) affect ecosystem services at different spatial and temporal scales (Bennett et al. 2015). For example, species richness can influence ecosystem services such as pollination and pest control whereas abundance can impact biomass production and nutrient cycling (Soliveres et al. 2016). The presence of more species increases the likelihood of an ecosystem to retain a wide range of functional traits. This, in turn, facilitates better ecosystem functioning or provision of services and increases resilience to any potential disturbance compared with communities with fewer species (Brockhoff et al. 2017).

3.4.1 Pollination

Wild pollinators such as bees, butterflies, birds and bats are fundamental to the reproduction and persistence of over 85% of wild flowering plants globally (Ollerton et al. 2011). Wild pollinators directly affect the productivity of 75% of globally important crops and are attributed with contributing up to an annual market value of USD 577 billion (Potts et al. 2016). A global study found that pollinator richness increased crop yields across 89 different crop systems (Dainese et al. 2019). Conversely, the absence of pollination can reduce global food production by 5–8% (Aizen et al. 2009) and risk the nutritional health of up to 56% of the human population in developing countries (Ellis et al. 2015). However, the diversity and complementarity of functional traits in pollinators is more important than the pollinator species richness, as evidenced in an experimental study in Göttingen, Germany (Fründ et al. 2013). In some parts of the world, for example Africa, with its heterogeneous landscapes and ecosystems, the contribution of animal pollinators to biological diversity remains poorly researched and understood.

3.4.2 Seed dispersal

Although many seeds are dispersed by wind, herbivore and frugivore animals also play an important role in seed dispersal. For instance, 68% of tree species are dispersed by animals in Mexico (Cortés-Flores et al. 2013). Moreover, passage of seeds through the gut of some mammals also enhances seed germination for some species (Campos-Arceiz and Blake 2011). The loss of seed-dispersing species can mean that fruiting trees are

replaced by wind-dispersed species, leading to homogenization of plant communities (Brodie and Aslan 2012). Thus, seed dispersal by animals contributes significantly to maintaining tree community structure and ecosystem services in the tropics (Markl et al. 2012; Brockerhoff et al. 2017).

3.4.3 Pest control

Control of crop pests by their natural enemies such as birds, bats and mammals is an important ecosystem service that supports agriculture (García et al. 2018). Biological pest control is more efficient in complex landscapes with heterogenous habitats where natural pest enemies are diverse and abundant (Chaplin-Kramer et al. 2011). For instance, insectivorous bats and birds play a key role in limiting arthropod abundance and pest outbreaks in diverse agroecological systems (Veres et al. 2013; Martin et al. 2016; Voigt and Kingston 2016). Moreover, natural pest control has always been found to be effective in oil palm landscapes where macaques can potentially regulate rodent populations, with each group feeding up to 3,000 rodents per year, as evidenced in Malaysia (Holzner et al. 2019).

3.4.4 Biomass production

Biodiversity promotes primary productivity and its temporal stability at a landscape scale (Oehri et al. 2017). For instance, a synthesis of 67 empirical studies shows that species richness significantly increases biomass production across a range of taxa and ecosystems (Duffy et al. 2017). Conversely, loss of biodiversity from a trophic group can reduce biomass production, resulting in less efficient resource capture, particularly in plants (Cardinale et al. 2012; Liang et al. 2016; Brose and Hillebrand 2016).

3.4.5 Carbon sequestration

Forest ecosystems are the largest land carbon sink, accounting for more than half of the carbon stored in terrestrial ecosystems (Hui et al. 2015). The major drivers of carbon accumulation across above- and belowground layers and soil are plant species richness and functional diversity (Lange et al. 2015; Brockerhoff et al. 2017). The estimated monetary value of biodiversity in sequestering carbon is considered to be up to USD 3.1 trillion (Isbell et al. 2017). Thus, biodiversity plays an important role in mitigating climate change by significantly reducing carbon emissions (Chen et al. 2018).

3.4.6 Nutrient cycling

Biodiversity influences biogeochemical cycles in myriad ways (Tully and Ryals 2017). For instance, plants sequester carbon, thereby producing soil biodiversity, whereas microorganisms such as bacteria, protozoa, fungi and invertebrate animals decompose organic matter and make nutrients available for plants (van der Heijden et al. 2016). Nitrogen-fixing trees maintain and enhance soil fertility by cycling atmospheric nitrogen, thereby increasing yields (Ajayi et al. 2011). Conversely, decreasing plant and soil diversity can alter decomposition pathways and nutrient cycling (Balvanera et al. 2006; Bender et al. 2016).

3.4.7 Ecosystem resilience

Biodiversity regulates ecosystem resilience by maintaining ecosystem functions and services through a range of mechanisms at species, community and landscape levels (Oliver et al. 2015; Mori et al. 2017). For instance, plant trait diversity maintains resilience in Amazon forests' biomass and thus acts as an insurance against climate change impacts (Sakschewski et al. 2016). Meanwhile, soil biodiversity plays an important role in regulating plant tolerance to stress, thereby also contributing to ecosystem stability (Yang et al. 2018).

3.4.8 Cultural services

Cultural services from biodiversity are crucial in enhancing the physical, mental and psychological well-being of human societies (Maller et al. 2006; Abraham et al. 2010; Russell et al. 2013). For instance, ecosystem services from biodiversity provide various health benefits such as lowering blood pressure, relieving stress and mental fatigue, and reducing crime and the tendency for aggressive behavior (Sandifer et al. 2015; Hausmann et al. 2016). Moreover, nature promotes social integration and contributes to the integrity of personal or community identity (Maller et al. 2006). For instance, Indigenous communities often link forest landscapes and biodiversity to tribal identities, kinship, customs and protocols (Gould et al. 2014; Lyver et al. 2017; Yuliani et al. 2018).

3.5 Managing landscapes for biodiversity and livelihoods

Effective management of landscapes for both biodiversity and livelihoods requires incorporating biodiversity at the design stage rather than considering it as a response to a conservation initiative. Land management strategies also need to consider the simultaneous interactions between multiple trophic levels and ecosystem services, and potential trade-offs between biodiversity, ecosystem services and livelihoods at both local and landscape scales (Macfadyen et al. 2012). Optimizing synergies and managing trade-offs based on empirical information and adapting management strategies to specific socioeconomic conditions are crucial for maintaining and enhancing both biodiversity and livelihoods in multifunctional landscapes (Kremen and Merenlender 2018).

3.5.1 Multiple trophic levels and ecosystem services

Multifunctional landscapes are complex and various ecosystem services interact with and impact these systems simultaneously (O'Farrell and Anderson 2010; Raudsepp-Hearne et al. 2010; Soliveres et al. 2016). Similarly, biodiversity loss occurs across various taxa, and the functional effects of any trophic group may depend on the abundance and diversity of others (Hughes et al. 2016). Therefore, only focusing on a single trophic group or an ecosystem service may lead to underestimating the functional importance of biodiversity and multiple ecosystem services. For instance, an analysis of the relationships between the species richness and abundance of 4,600 taxa and 14 different

ecosystem services in 150 grasslands shows that high species richness in multiple trophic groups affected ecosystem services more strongly than richness in any individual trophic group (Soliveres et al. 2016). This makes it vital to incorporate simultaneous impacts of any anthropogenic pressure on multiple trophic levels and ecosystem services in effective landscape management strategies.

3.5.2 Trade-offs between biodiversity and ecosystem services

A range of trade-offs can occur between biodiversity and ecosystem services and between different ecosystem services (Howe et al. 2014; van der Plas et al. 2018). For instance, trade-offs between agricultural production and biodiversity (Chapin III et al. 2000; Macfadyen et al. 2012) and between carbon storage and other ecosystem services (Goldstein et al. 2012) are well documented. Moreover, the relationships between ecosystem services and biodiversity can also change across landscapes of differing complexity (Birkhofer et al. 2018). For example, a study on the relationship among eight ecosystem services and species richness of five taxonomic groups in cereal farming systems showed that biodiversity increases with increasing landscape complexity, but there was no evidence of a similar positive impact on ecosystem services (Birkhofer et al. 2018). Thus, it is necessary to explicitly incorporate both biodiversity and ecosystem services in landscape management strategies, as promoting one might not necessarily lead to a positive impact on the other (Macfadyen et al. 2012).

3.5.3 Trade-offs between biodiversity conservation and livelihoods

Trade-offs between conservation and economic development objectives to ensure livelihoods can potentially be reconciled by targeting management interventions on different components of a landscape (Sayer et al. 2013). However, identification of the optimal allocation of different management options at the landscape scale can also be a challenge (Verhagen et al. 2018). This requires the prioritization of local habitats that are important in providing ecosystem services such as biological pest control (Landis 2017) and pollination services (Garibaldi et al. 2017). For instance, agricultural landscapes can be managed to optimize biodiversity, ecosystem services and livelihoods by incorporating agroforestry, aquaculture, conservation tillage, integrated nutrient management, integrated pest management, crop–livestock integration and water harvesting techniques (Garibaldi et al. 2017).

3.5.4 Landscape heterogeneity and connectivity

Landscape composition (proportion of land-use types) and configuration (size, shape and arrangement of land-use patches) play an important role in determining biodiversity in heterogeneous landscapes (Dufлот et al. 2017; Martin et al. 2019). For example, a review of 49 studies showed that a higher level of landscape configuration (edge density) increased pollinator and natural enemy abundance significantly, leading to improved pollination and pest control across European agroecosystems (Martin et al. 2019). Similarly, an increase in compositional and configurational landscape heterogeneity decreased arthropod abundance in rice cultivation (Dominik et al. 2018), whereas landscape composition had a relatively stronger effect on plant and vertebrate communities (Herrera et al. 2016; Dufлот et al. 2017). Therefore, it is crucial to incorporate the impacts of both landscape composition and configuration in land-use planning.

3.5.5 Land tenure, rights and social equity

Since Indigenous communities manage over a quarter of the world's land surface, addressing their tenure, rights and sharing benefits is essential to achieving conservation goals (Garnett et al. 2018). Strengthening stakeholder capacity and facilitating their active involvement in every stage from planning to implementation can contribute significantly in addressing these issues (Zanzanaini et al. 2017). Understanding how different stakeholders benefit from ecosystem services and their preferences for valuing services and how customary institutions are acknowledged by formal institutions are also crucial in evaluating trade-offs and their implications for livelihoods and well-being (Bennett et al. 2015). This facilitates a better understanding of stakeholders' multifaceted perceptions around ecosystem services and thus leads to effectively incorporating those in management systems (Martín-López et al. 2012).

3.6 Biodiversity monitoring in multifunctional landscapes

Biodiversity monitoring is key to better understanding how biodiversity responds to drivers of change, its effects on ecosystem services and how to best assess the progress of any conservation intervention (Luque et al. 2018). Setting a frame of reference to track progress and choosing suitable indicators reflecting key aspects of biodiversity response can facilitate objective evaluation of conservation initiatives. Moreover, remote sensing and modeling techniques and community-based monitoring programs can contribute to large-scale data collection, interpretation and informed decision-making with the active participation of local stakeholders.

3.6.1 Frame of reference to track progress

The progress of conservation interventions can be evaluated against a clearly specified frame of reference that is either a temporal baseline, i.e. a known biodiversity level at a fixed point in the past or present, or a counterfactual such as an alternative scenario that would have occurred without the intervention (Bull et al. 2014). This frame of reference should be set at an appropriate scale, depending on the context (Mihoub et al. 2017). Although widely used in climate change and restoration assessments, the importance of identifying an appropriate frame of reference to track progress is still largely overlooked in many conservation approaches (Bull et al. 2014), particularly at the landscape scale (Reed et al. 2017).

3.6.2 Selecting suitable biodiversity indicators

Biodiversity indicators are widely used tools to monitor and evaluate rates of biodiversity change, habitat condition and the progress in conservation interventions (Mcowen et al. 2016; Bal et al. 2018; Han et al. 2020). A systematic decision framework for indicator selection can make it feasible for land managers and stakeholders to assess biodiversity responses and facilitate effective decision-making (Tzivilakis et al. 2016). This framework can draw from existing international guidelines such as Biodiversity Indicators Partnership (Addison et al. 2018; Rochette et al. 2019). These indicators need to be unambiguously defined and measurable at appropriate scales while also

considering management effectiveness and budget constraints (Valerio et al. 2016; Bal et al. 2018; Rochette et al. 2019). Moreover, these indicators should include measures to track social outcomes linked to biodiversity such as capacity building and levels of anthropogenic pressures (Mcowen et al. 2016).

3.6.3 Citizen science programs

Citizen science, i.e. the practice of engaging the public in a scientific process to produce information that can be used by scientists, decision-makers or the public, is emerging as a powerful tool for tackling conservation challenges (McKinley et al. 2017; Strasser et al. 2019). It can improve conservation efforts by building scientific knowledge through active public participation and by facilitating informed and effective land management decisions and policy-making (Kobori et al. 2016; McKinley et al. 2017). Although most of the existing citizen science programs are currently focused on North America and Europe, various community-based monitoring programs actively operate in Africa and Asia (Chandler et al. 2017). These community-based monitoring (CBM) programs are designed, interpreted and implemented for effective management by local communities (Danielsen et al. 2014). Meanwhile, there is early evidence of the potential for citizen science approaches to improve conservation and development decision-making and outcomes in landscape approaches (Sayer et al. 2015). Citizen science programs can potentially contribute significantly to generating large-scale data on species distribution, species abundance and ecosystem services (Bonney et al. 2016; Chandler et al. 2017), while also creating public awareness, empowering local communities and improving conservation outcomes (McKinley et al. 2017).

3.6.4 Use of remote-sensing techniques

Remote-sensing techniques based on high-resolution and multispectral satellite imagery are widely used to monitor biodiversity, ecosystem services and land-use/land-cover changes at both spatial and temporal scales (Vihervaara et al. 2017; Luque et al. 2018). Moreover, recent technologies from drones and airborne lidar (light detection and ranging) systems generating very high-resolution (VHR) images can improve biodiversity monitoring and ecosystems at both local and regional scales (Guo et al. 2017). Novel techniques to estimate species richness and compositional turnover (β -diversity) from airborne or satellite remote sensing can help provide faster and more effective biodiversity monitoring (Rocchini et al. 2018). Increasing the availability and accessibility of processed remotely sensed and geo-referenced data sources at fine spatial and temporal resolutions through open access databases can be particularly useful (Reed et al. 2020).

3.6.5 Use of modeling and predictions

Landscape ecological modeling can contribute significantly to our understanding of socioeconomic drivers of land use change and their impact in multifunctional landscapes (Synes et al. 2016). Moreover, social–ecological models can be useful tools for evaluating trade-offs between conserving biodiversity and multiple ecosystem services and providing temporal and spatial projections of future scenarios that can facilitate better decision-making (Mori et al. 2017). For instance, ecosystem services models that

incorporate biodiversity conservation, such as the Integrated Valuation of Environmental Services and Tradeoffs (InVEST) model (Nelson et al. 2009; see also Chapter 6) can be effective in incorporating the complexity of interacting ecosystem services at multiple scales and generating future land use scenarios for informing policy (Swayne et al. 2010).

3.7 Biodiversity assessment in the three landscapes

3.7.1 Western Wildlife Corridor landscape, Northern Ghana

Fauna and floristic biodiversity

The North Ghanaian savannah that hosts the Western Wildlife Corridor (WWC) is generally described as an area rich in wildlife and floristic biodiversity. Indeed, the forest reserves found there are important refuges for many species of mammals, primates, reptiles, birds and rodents, among others (Husseini et al. 2015; Owusu-Ansah 2018).

In terms of floristic biodiversity, the woody species encountered in the area are mainly *Vitellaria paradoxa*, *Combretum* spp., *Acacia* spp., *Anogeissus leiocarpa*, *Azelia africana*, *Burkea africana*, *Isobertia doka*, *Terminalia* spp., *Adansonia digitata*, *Boscia senegalensis*, *Calotropis procera*, *Lannea microcarpa*, *Acacia goudaensis*, *Acacia polyacantha*, *Tamarindus indica*, *Balanites aegyptiaca*, *Annona senegalensis*, *Bombax* spp., *Diospyros mespiliformis*, *Parkia biglobosa*, *Pterocarpus erinaceus*, forming most of the woody savannas. Forest galleries border the main rivers and host species such as *Daniellia oliveri*, *Terminalia* spp., *Anogeissus leiocarpa* and *Khaya senegalensis* (Bouché 2007; Husseini et al. 2015; Owusu-Ansah 2018; see also Chapter 8).

Importance, constraints and measures of biodiversity conservation

Compared to the high forest zone of Ghana, the savanna ecological zone is timber-poor and hence is not suitable for commercial timber production. However, it still plays a key role in meeting the socioeconomic, cultural and other ecosystem services needs of people (Asase and Oteng-Yeboah 2012). The savanna woodlands ecosystem comprises multifunctional areas that can contribute to reducing rural poverty, supporting the local economy and maintaining biological diversity (IUCN 2012). They provide important regulating, provisioning and cultural services, and are a critical refuge for native biodiversity. In terms of provisioning services, this ecosystem produces about 70% of Ghana's total supply of firewood and charcoal (World Bank 2002). It shelters several Ghanaian staples, including root tubers such as yam, cereals such as millets, assorted vegetables and nuts. Savanna bushmeat (e.g. rodents, antelopes, reptiles) is estimated to provide 12% of rural people's protein intake, while it is also a source of income (Ibid.). With its large tracts of grasslands, the WWC hosts most of Ghana's livestock population, significantly contributing to the protein needs of the country. Other useful ecosystem services include medicinal plants, roofing grasses and fencing poles. The savanna woodlands also have beneficial effects on the local climate and constitute a natural barrier to the desiccating harmattan winds from the Sahara, helping to maintain a favorable microclimate for agricultural production in the south.

Shea trees (*Vitellaria paradoxa*) are indigenous to the landscape and are important for the regulation services within the agroforestry system and for the livelihood of people, particularly women (Anang et al. 2011). The fruits are harvested by women to produce shea butter or shea kernel, which are consumed locally, but increasingly marketed as a global commodity in recent years. However, this ecosystem is facing pressure, as shea trees are being lost to indiscriminate charcoal production as a response to the increasing urban demand (Lurimuah 2011; Dapilah et al. 2019). In addition, with the global demand increasing and the lack of investment in the shea value chain, the transformation of the shea nut has negative impacts as it is energy intensive and therefore fuelwood is often harvested in large quantities for this purpose (Jibreel et al. 2013; Jasaw et al. 2017).

African rosewood (*Pterocarpus erinaceus*) occurs in the Northern Region, particularly within the catchment area of the Mole and Bui National Parks. Recent botanical surveys carried out in northern Ghana estimate the abundance of the African rosewood species to be 82 trees per 40 ha (Ghana Shea Landscape REDD+ Project Concept Note 2017). The exploitation of this species is subject to many conflicts and a heated debate in the area, as demand from international timber markets (China) is increasing (Treanor 2015). To curb overexploitation, a ban was placed on exports in 2012 but was later lifted as salvage permits were given during the construction of a major road network and hydropower station in the Northern Region in 2013, which led again to overexploitation and the subsequent reintroduction of the ban in January 2014. The species was not targeted for local illegal chain-sawed lumber until the surge in demand in 2013 (Dumenu and Bando 2016). There is potential to support the development and management of rosewood as a high-value source of revenue. In terms of sustainable management of the biodiversity of both shea and rosewood ecosystems, understanding their ecological characteristics and dynamics including species abundance, distribution, mortality and regeneration patterns is crucial (Dumenu and Bando 2016).

As in other drylands regions, threats to biodiversity in the area come from climate change, land degradation and deforestation. Thus, the survival of indigenous land varieties of important food crops and an increasing number of medicinal plant species is being threatened. High levels of human and animal pressure on natural resources, uncontrolled bush fires, agricultural expansion, deforestation and the replacement of indigenous varieties with imported ones are the most cited threats to biodiversity in the region (Mensah et al. 2016). Those issues are exacerbated by the changing climate, with a higher seasonal variability and more extreme events expected in the future. Consequently, many wild species such as elephants, for example, are restricted to a few protected areas. Because of high human impact, elephant migration is now essentially nonexistent in both the eastern and western corridors. However, the existence of a third, lesser known corridor has been revealed between Mole National Park and Bontioli in Burkina Faso through the Gbele Resource Reserve (Bouché 2007).

For many years, the biodiversity efforts of the government were concentrated in the Ghanaian humid zone, and the first draft of the National Biodiversity Strategy and Action Plan neither included the different ethnic and cultural perspectives of the savanna zone nor addressed land degradation issues in the northern savanna regions. Meanwhile, more awareness and efforts are needed to address the biodiversity loss in

the Northern Region. Indeed, inadequate relevant information has been pointed out as a drawback to the implementation of the National Biodiversity Strategy for Ghana (Hackman 2014).

In situ biodiversity efforts such as those undertaken by the Plant Genetic Resource Center (PGRC), which operates under the auspices of the Ministry of Environment, Science and Technology (MEST) and is based at Bunso, have a basic assignment to collect, conserve, characterize and document plant genetic resources in the country. Besides its *ex situ/in vivo* facilities, the PGRC maintains an arboretum that contains timber species, medicinal plants, non-timber species and fruit trees. The PGRC works with other institutions related to the northern savannah landscape, such as the Savanna Agricultural Research Institute (SARI) and NGOs working with communities to preserve biological resources and natural habitats, including sacred groves.

In the face of the multiple threats affecting biodiversity conservation, economic incentives through livelihood support activities have been promoted by numerous projects as instruments for natural resource and biodiversity conservation at the fringes of protected areas (Ekpe et al. 2014).

3.7.2 Kalomo District, Zambia

Zambia is well endowed with natural resources and biological diversity (GRZ 2015a) that are an importance source of food, nutrition and vitamins, especially to rural households. As elsewhere, human activities have led to unprecedented levels of biodiversity loss in the last few decades (Hanks 2019). Consequently, one of the goals of Zambia's second National Biodiversity Strategy and Action Plan (NBSAP-2) is to "address the underlying drivers of biodiversity loss by mainstreaming biodiversity across government and society" (GRZ 2015a, p. 32). This is underpinned by several policies designed to stem biodiversity loss in affected sectors (GRZ 2015a).

The major drivers of biodiversity loss in Zambia are various, including economic; policy and regulatory; social, environmental, cultural and demographic; political; scientific; and technological. Agriculture, whether subsistence or commercial, remains one of the main drivers of not only habitat loss but also biodiversity loss. The annual deforestation rate in Zambia is 276,021 ha per annum or 6% of the total forest cover (GRZ et al. 2016) and this has a tremendous impact on biodiversity. Relatedly, practices such as intensive mono-cropping, burning of bush areas for land preparation, use of synthetic fertilizers, and the associated poor disposal of herbicides and insecticides further contribute to the loss of biodiversity.

Government structures are weakly empowered and supported in reducing biodiversity loss due to insufficient resources. Further, conflicting mandates among institutions that issue provisions that adversely affect biodiversity; for example, trade policies in the external sector that allow duty-free importation of fishing gear and the issuing of mining operation licenses by the Ministry of Mines and Minerals Development in protected areas (Matakala et al. 2015) impede progress. In addition, biodiversity management is hampered by low investment in and funding of human resources and physical infrastructure. Key biodiversity sectors such as forestry, wildlife and fisheries

that fall under environmental and natural sectors are lowly prioritized and hence get a low share of the national budget. Actual allocations for environmental protection have over the years been less than 50% of the budgeted amounts (GRZ 2015b).

Lately, a rise in invasive alien species has been noted and they too are contributing to biodiversity loss. Among the invasive species in Zambia are the water hyacinth (Kafue weed), *Salvinia molesta* (Kariba weed), and *Tithonia diversifolia* (Mabeta et al. 2018). The *Lantana camara*, a weed, and *Toona ciliata* are posing serious threats to forestry plantations in the Copperbelt Province as well as near the Victoria Falls in the Livingstone area (GRZ et al. 2016).

Biodiversity loss in Zambia is increasing, due to a host of drivers wherein economic drivers are the largest contributor. Further compounded by emerging issues such as climate change, invasive alien species and mining, they collectively pose serious threats for sustainable biodiversity management in Zambia. Improved extension services and more integrated decision-making can increase awareness and capacity on the diffusion of technologies that increase efficiency and productivity, such as conservation agriculture, and reduced utilization of water, fertilizers and pesticides or other inputs that adversely affect biodiversity.

3.7.3 Kapuas Hulu Regency, West Kalimantan, Indonesia

Located in the northeastern part of West Kalimantan Province and bordering Sarawak (Malaysia), Kapuas Hulu Regency (31,162 km²) is one of the last rainforest frontiers of Borneo and the hydrological powerhouse of the whole province. Very remote until the 1980s, it now has a long history of collaboration on transboundary management and conservation between Malaysia and Indonesia. Starting in 1993, transboundary biodiversity conservation areas (TBCAs) were delineated, several biodiversity expeditions were financed by the International Tropical Timber Organization (ITTO 1998), and more recently, there has been involvement in transnational cooperation under the Heart of Borneo (HoB) initiative (Wulffraat et al. 2017).

With 73% of forest cover in 2019 (Laumonier et al. 2020a), the region is biodiversity rich. However, competing perspectives over land exist between local government agencies (planning bureau, forestry, watershed, agriculture, national park authorities, fisheries, tourism), local communities, local NGOs and the private sector. The current land use has been influenced by several issues of unclear or even ambiguous regulations and conflicting recommendations made by institutions related to natural resource management, tenurial conflicts, exclusion of ecosystem services in land-use planning processes and the agenda of large-scale businesses. Those issues have impacts on forest clearance and biodiversity loss and are threatening local communities' livelihoods and cultural identity (Shantiko et al. 2013). In the pursuit of development, land allocated for alternative use to forestry has increased by more than 19% in the revised spatial plan of 2011 (PERDA Kabupaten Kapuas Hulu 2014).

Indigenous communities still manage land using traditional practices, i.e. swidden agriculture to grow crops such as paddy, maize, cassava, tubers and vegetables. The agricultural land acquired by clearing forest or secondary forest is systematically left

to lie fallow for a period after paddy rice is harvested. Perennial crops, mainly rubber, provide a ready source of cash income and are often grown to supplement other crops such as pepper, fruits and illipe (*tengkawang*) nuts. The forest is essential for the people in Kapuas Hulu, especially for food (meat, fruits and vegetables), medicines and traditional crafts (baskets and mats). In general, although economic activities in the district and rural areas are emerging, subsistence activities still play a central role, for instance, food provisioning from fallows, fishing and the gathering of forest products. In the south, many communities are involved in environmentally devastating illegal gold mining operations near almost all rivers.

The diversity of ecosystems and their importance for the conservation of Borneo's biodiversity led to the establishment of two national parks in Kapuas Hulu (an unusual situation for Indonesia): Betung Kerihun National Park, which has a variety of lowland, hill and mountain forest ecosystems; and Danau Sentarum National Park, the only remaining extensive wetlands in Borneo with a unique ecosystem of interconnecting seasonal lakes, peat swamps and periodically inundated freshwater swamp forests (Giesen 2000; see also Chapter 10). To curb the massive illegal logging occurring in the area in the 1990s and up until 2003, and also to secure the hydrological power function of the Kapuas River Basin (98,700 km²) for the rest of the province, the local government declared the regency a 'conservation regency' in 2003. More recently, a World Wide Fund for Nature initiative advocated the establishment of a biodiversity corridor between the two parks (Widmann et al. 2012). Furthermore, the whole regency was registered as an official UNESCO Man and the Biosphere (MAB) zone in 2018.

The complex geomorphology and biophysical characteristics of the Kapuas River Basin brought about a high diversity of habitats and vegetation types. The Kapuas originates from the mountain range in the east, descends westward into flat lowlands less than 50 m in elevation to reach its delta near the provincial capital city of Pontianak, 900 km away (MacKinnon et al. 1996). This low inclination resulted in the formation of a floodplain, wetlands and lakes in the upstream part of the river, surrounded by the mountain ranges of the Betung–Kerihun–Upper Kapuas mountains in the north, the Muller Mountains in the east, and the towering sandstone Madi Plateau in the south. With mean annual precipitation of 4231 mm (range 2863–5517) (WorldClim 2018), the entire region has a very humid climate, but prolonged droughts can occur, often during El Niño years. The wetlands of the Danau Sentarum system receive approximately 25% of the annual flood flow of the Kapuas River during the wet season. Conversely, 50% of the downstream flow during the dry season originates in these wetlands (Klepper 1994). Hidayat et al. (2017) used a combination of satellite remote sensing and observations from field campaigns to study the hydrological dynamics of the Kapuas Basin.

For ecology and biodiversity assessments, the Danau Sentarum National Park area has received far greater attention compared with the rest of the regency. Since the 1990s, it has been an active research site for ecologists researching flora and vegetation (several swamp forest types, from forests that are periodically inundated with freshwater to deep peat swamp forests; Kerangas and Kerapah), fauna (fish, crocodiles, birds, proboscis monkeys and endangered Bornean orangutans), as well as human resource use (honey, fisheries, turtles, rattan, timber), culture, and social and environmental economics (see

review by Aglionby 2010). In contrast, all the rest of the regency, including the other national park, Betung Kerihun, has received very little attention besides the original transboundary expeditions and baseline fauna and flora data (Soedjito 1999; ITTO 2013). The number of tree species in the lowlands and hills is estimated to be around 1200, encompassing at least 120 species of dipterocarp, numerous palms and orchids, which are replaced at higher altitude with the 'Montane rainforest of the Müller- and Upper Kapuas Mountains' floristic region (Raes 2009). The fauna of the lowlands and hills is also very diverse, with 300 species of birds (25 endemic to Borneo), at least 180 fish species and at least 54 mammals (including 8 primates: Bornean orangutan, Müller's Bornean gibbon, white-fronted surili, maroon leaf monkey, southern pig-tailed macaque, crab-eating macaque, Sunda slow loris and Horsfield's tarsier) (Aglionby 2010). All the southern hills and mountains had never been surveyed until recently (Weihreter 2014; Labrière et al. 2015; Boissière et al. 2017; Laumonier et al. 2020b).

Ongoing development has introduced changes and brought new pressures, which have influenced the long-established interactions between the people and their landscape. Oil palm plantations have expanded across West Kalimantan in recent years. They are now advancing toward Kapuas Hulu, with the establishment of oil palm plantations spreading from the west of the regency, reaching the 'biodiversity corridor' between the two national parks in the north, and spreading into the south (Yuliani 2010; Leonald and Rowland 2016). The potential impact of the growth of oil palm plantations on biodiversity and ecosystem functions presents a significant challenge for the regency, which is faced with the need to mitigate the impacts of economic development and of maintaining ecosystem services, preserving the environmental and social functions that they provide.

As a designated conservation district and MAB zone, the regency government of Kapuas Hulu made commitments to conserve its natural resources. However, the challenge will be to ensure that this can be done while creating economic development opportunities that contribute to poverty alleviation and support the needs of the local population. The landscape approach implemented for two of its watersheds (see Chapter 10) will facilitate this process.

Conclusion

Biodiversity plays an important role in safeguarding food security, livelihoods and human well-being. Thus, incorporating biodiversity into integrated landscape management strategies is crucial for reconciling conservation and livelihoods in multifunctional landscapes. This requires careful consideration of trade-offs and synergies between biodiversity, ecosystem services and livelihoods at both local and landscape levels. Use of suitable biodiversity indicators, remote sensing and modeling techniques, and citizen science programs can facilitate effective monitoring of a biodiversity response to conservation interventions. This can further lead to informed decision-making and the sustainable management of landscapes for both biodiversity and livelihoods.

References

- Abraham A, Sommerhalder K and Abel T. 2010. Landscape and well-being: A scoping study on the health-promoting impact of outdoor environments. *International Journal of Public Health* 55: 59–69.
- Addison PFE, Carbone G and McCormick N. 2018. *The Development and Use of Biodiversity Indicators in Business: An Overview*. Gland, Switzerland: IUCN. vi + 16pp.
- Aglionby J. 2010. Danau Sentarum National Park, Indonesia: A historical overview. *Borneo Research Bulletin* 41: 20–35.
- Agrawal A, Cashore B, Hardin R, Shepherd G, Benson C and Miller D. 2013. *Economic contributions of forests*. Background paper prepared for the United Nations Forest on Forests (UNFF), 10th Session, Istanbul, Turkey. (<http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.269.2378&rep=rep1&type=pdf>).
- Aizen MA, Garibaldi LA, Cunningham SA and Klein AM. 2009. How much does agriculture depend on pollinators? Lessons from long-term trends in crop production. *Annals of Botany* 103: 1579–88.
- Ajayi OC, Place F, Akininifesi FK and Sileshi GW. 2011. Agricultural success from Africa: The case of fertilizer tree systems in southern Africa (Malawi, Tanzania, Mozambique, Zambia and Zimbabwe). *International Journal of Agricultural Sustainability* 9: 129–36.
- Alvarez I, and Lovera S. 2016. New times for women and gender issues in biodiversity conservation and climate justice. *Development* 59: 263–5.
- Alves RR. and Rosa IM. 2007. Biodiversity, traditional medicine and public health: where do they meet? *Journal of Ethnobiology and Ethnomedicine* 3(1): 14.
- Anang BT, Akuriba M and Alesane A. 2011. Charcoal production in Gushegu District, Northern Region, Ghana: Lessons for sustainable forest management. *International Journal of Environmental Sciences* 1: 1944–1953.
- Angelsen A, Jagger P, Babigumira R, Belcher B, Hogarth NJ, Bauch S, Börner J, Smith-Hall C and Wunder S. 2014. Environmental income and rural livelihoods: A global-comparative analysis. *World Development* 64:S12–S28.
- Asase A, Oteng-Yeboah AA. 2012. Plants used in Wechiau Community Hippopotamus Sanctuary in Northwest Ghana. *Journal of Ethnobotany Research & Applications* 10: 605–618.
- Bal P, Tulloch AI, Addison PF, McDonald-Madden E and Rhodes JR. 2018. Selecting indicator species for biodiversity management. *Frontiers in Ecology and the Environment* 16: 589–98.
- Balvanera P, Pfisterer AB, Buchmann N, He J-S, Nakashizuka T, Raffaelli D and Schmid B. 2006. Quantifying the evidence for biodiversity effects on ecosystem functioning and services: Biodiversity and ecosystem functioning/services. *Ecology Letters* 9: 1146–56.
- Barlow J, França F, Gardner TA, Hicks CC, Lennox GD, Berenguer E, Castello L, Economo EP, Ferreira J, Guénard B, et al. 2018. The future of hyperdiverse tropical ecosystems. *Nature* 559: 517–26.

- Barlow, J, Lennox GD, Ferreira J, Berenguer E, Lees AC, Nally RM, Thomson JR, Ferraz SF de B, Louzada J, Oliveira VHF, et al. 2016. Anthropogenic disturbance in tropical forests can double biodiversity loss from deforestation. *Nature* 535: 144–7.
- Barnosky AD, Matzke N, Tomiya S, Wogan GOU, Swartz B, Quental TB, Marshall C, McGuire JL, Lindsey EL, Maguire KC, et al. 2011. Has the Earth's sixth mass extinction already arrived? *Nature* 471: 51–7.
- Baudron F, Tomscha SA, Powell B, Groot JCJ, Gergel SE and Sunderland T. 2019. Testing the various pathways linking forest cover to dietary diversity in tropical landscapes. *Frontiers in Sustainable Food Systems* 3:97. <https://doi.org/10.3389/fsufs.2019.00097>.
- Bender SE, Wagg C and van der Heijden MGA. 2016. An underground revolution: Biodiversity and soil ecological engineering for agricultural sustainability. *Trends in Ecology & Evolution* 31: 440–52.
- Bennett EM, Cramer W, Begossi A, Cundill G, Díaz S, Egoh BN, Geijzendorffer IR, Krug CB, Lavorel S, Lazos E, et al. 2015. Linking biodiversity, ecosystem services, and human well-being: Three challenges for designing research for sustainability. *Current Opinion in Environmental Sustainability* 14: 76–85.
- Bharucha Z and Pretty J. 2010. The roles and values of wild foods in agricultural systems. *Philosophical Transactions of the Royal Society B: Biological Sciences* 365: 2913–26.
- Birkhofer K, Andersson GKS, Bengtsson J, Bommarco R, Dänhardt J, Ekbom B, Ekroos J, Hahn T, Hedlund K, Jönsson AM, et al. 2018. Relationships between multiple biodiversity components and ecosystem services along a landscape complexity gradient. *Biological Conservation* 218: 247–53.
- Boissière M, Herold M, Atmadja S and Sheil D. 2017. The feasibility of local participation in Measuring, Reporting and Verification (PMRV) for REDD+. *PLoS ONE* 12(5): e0176897.
- Bonney R, Phillips TB, Ballard HL and Enck JW. 2016. Can citizen science enhance public understanding of science? *Public Understanding of Science* 25: 2–16.
- Bouché P. 2007. Northern Ghana elephant survey, *Pachyderm* 42(42): 58–69.
- Brocknerhoff EG, Barbaro L, Castagneyrol B, Forrester DI, Gardiner B, González-Olabarria JR, Lyver PO, Meurisse N, Oxbrough A, Taki H, et al. 2017. Forest biodiversity, ecosystem functioning and the provision of ecosystem services. *Biodiversity and Conservation* 26: 3005–35.
- Brodie JF and Aslan CE. 2012. Halting regime shifts in floristically intact tropical forests deprived of their frugivores. *Restoration Ecology* 20: 153–7.
- Broegaard RB, Rasmussen LV, Dawson N, Mertz O, Vongvisouk T and Grogan K. 2017. Wild food collection and nutrition under commercial agriculture expansion in agriculture-forest landscapes. *Forest Policy and Economics* 84: 92–101.
- Brondizio ES, Settele J, Díaz S and Ngo HT. 2019. *Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. Bonn, Germany: IPBES Secretariat.
- Brose U and Hillebrand H. 2016. Biodiversity and ecosystem functioning in dynamic landscapes. *Philosophical Transactions of the Royal Society B: Biological Sciences* 371:20150267.

- Bull JW, Gordon A, Law EA, Suttle KB and Milner-Gulland EJ. 2014. Importance of baseline specification in evaluating conservation interventions and achieving no net loss of biodiversity: No net loss and baseline specifications. *Conservation Biology* 28: 799–809.
- Campos-Arceiz A and Blake S. 2011. Megagardeners of the forest – the role of elephants in seed dispersal. *Acta Oecologica* 37: 542–53.
- Cardinale BJ, Duffy JE, Gonzalez A, Hooper DU, Perrings C, Venail P, Narwani A, Mace GM, Tilman D, Wardle DA, et al. 2012. Biodiversity loss and its impact on humanity. *Nature* 486: 59–67.
- Chandler M, See L, Copas K, Bonde AMZ, López BC, Danielsen F, Legind JK, Masinde S, Miller-Rushing AJ, Newman G, et al. 2017. Contribution of citizen science towards international biodiversity monitoring. *Biological Conservation* 213: 280–294.
- Chapin III FS, Zavaleta ES, Eviner VT, Naylor RL, Vitousek PM, Reynolds HL, Hooper DU, Lavorel S, Sala OE, Hobbie SE, et al. 2000. Consequences of changing biodiversity. *Nature* 405: 234–42.
- Chaplin-Kramer R, Dombeck E, Gerber J, Knuth KA, Mueller ND, Mueller M, Ziv G and Klein AM. (2014). Global malnutrition overlaps with pollinator-dependent micronutrient production. *Proceedings of the Royal Society B: Biological Sciences* 281(1794), 20141799.
- Chaplin-Kramer R, O'Rourke ME, Blitzer EJ and Kremen C. 2011. A meta-analysis of crop pest and natural enemy response to landscape complexity: Pest and natural enemy response to landscape complexity. *Ecology Letters* 14: 922–32.
- Chen S, Wang W, Xu W, Wang Y, Wan H, Chen D, Tang Z, Tang X, Zhou G, Xie Z, et al. 2018. Plant diversity enhances productivity and soil carbon storage. *Proceedings of the National Academy of Sciences of the United States of America* 115: 4027–32.
- Cortés-Flores J, Andresen E, Cornejo-Tenorio G and Ibarra-Manríquez G. 2013. Fruiting phenology of seed dispersal syndromes in a Mexican neotropical temperate forest. *Forest Ecology and Management* 289: 445–54.
- Cramer W, Egea E, Fischer J, Lux A, Salles J-M, Settele J and Tichit M. 2017. Biodiversity and food security: from trade-offs to synergies. *Regional Environmental Change* 17: 1257–9.
- Dainese M, Martin EA, Aizen MA, Albrecht M, Bartomeus I, Bommarco R, Carvalheiro LG, Chaplin-Kramer R, Gagic V, Garibaldi LA, et al. 2019. A global synthesis reveals biodiversity-mediated benefits for crop production. *Science Advances* 5(10):eaax0121.
- Danielsen F, Jensen PM, Burgess ND, Altamirano R, Alviola PA, Andrianandrasana H, Brashares JS, Burton AC, Coronado I, Corpuz N, et al. 2014. A multicountry assessment of tropical resource monitoring by local communities. *BioScience* 64: 236–51.
- Dapilah F, Nielsen JØ and Akongbangre JN. 2019. Peri-urban transformation and shared natural resources: the case of shea trees depletion and livelihood in Wa municipality, Northwestern Ghana. *African Geographical Review* 38(4): 374–389.

- Datta A, Anand MO and Naniwadekar R. 2008. Empty forests: Large carnivore and prey abundance in Namdapha National Park, north-east India. *Biological Conservation* 141: 1429–35.
- Delang CO. 2006. The role of wild food plants in poverty alleviation and biodiversity conservation in tropical countries. *Progress in Development Studies* 6: 275–86.
- Díaz S, Settele J, Brondízio E, Ngo H, Guèze M, Agard J, Arneth A, Balvanera P, Brauman K, Butchart S, et al. 2019. Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES secretariat, Bonn, Germany. 56 pages. <https://doi.org/10.5281/zenodo.3553579>
- Dominik C, Seppelt R, Horgan FG, Settele J and Václavík T. 2018. Landscape composition, configuration, and trophic interactions shape arthropod communities in rice agroecosystems. *Journal of Applied Ecology* 55: 2461–72.
- Duffy JE, Godwin CM and Cardinale BJ. 2017. Biodiversity effects in the wild are common and as strong as key drivers of productivity. *Nature* 549: 261–4.
- Dufлот R, Ernoult A, Aviron S, Fahrig L and Burel F. 2017. Relative effects of landscape composition and configuration on multi-habitat gamma diversity in agricultural landscapes. *Agriculture, Ecosystems & Environment* 241: 62–9.
- Dumenu WK, Bando W. 2016. Exploitation of African rosewood (*Pterocarpus erinaceus*) in Ghana: A situation analysis, *Ghana Journal of Forestry* 32: 1-15.
- Ekpe EK, Hinkle CR, Quigley MF and Owusu EH. 2014. Natural resource and biodiversity conservation in Ghana: the use of livelihoods support activities to achieve conservation objectives, *International Journal of Biodiversity Science, Ecosystem Services & Management* 10(4): 253-261. <https://doi.org/10.1080/21513732.2014.971056>.
- Ellis AM, Myers SS and Ricketts TH. 2015. Do pollinators contribute to nutritional health? *PLoS ONE* 10:e114805.
- Fisher M. 2004. Household welfare and forestry dependence in Southern Malawi. *Environmental and Development Economics* 9: 135-154.
- Fründ J, Dormann CF, Holzschuh A and Tscharntke T. 2013. Bee diversity effects on pollination depend on functional complementarity and niche shifts. *Ecology* 94: 2042–54.
- García D, Miñarro M and Martínez-Sastre R. 2018. Birds as suppliers of pest control in cider apple orchards: Avian biodiversity drivers and insectivory effect. *Agriculture, Ecosystems & Environment* 254: 233–43.
- Garibaldi LA, Gemmill-Herren B, D'Annolfo R, Graeub BE, Cunningham SA and Breeze TD. 2017. Farming approaches for greater biodiversity, livelihoods, and food security. *Trends in Ecology & Evolution* 32: 68–80.
- Garnett ST, Burgess ND, Fa JE, Fernández-Llamazares Á, Molnár Z, Robinson CJ, Watson JEM, Zander KK, Austin B, Brondizio ES, et al. 2018. A spatial overview of the global importance of indigenous lands for conservation. *Nature Sustainability* 1: 369–74.
- Ghana Shea Landscape REDD+ Project Concept Note. 2017. Ghana. *United Nations Development Programme (UNDP) and Ministry of Finance, Ghana*. <https://www>.

- greenclimate.fund/sites/default/files/document/16460-ghana-shea-landscape-redd-project.pdf.
- Giam X. 2017. Global biodiversity loss from tropical deforestation. *Proceedings of the National Academy of Sciences of the United States of America* 114: 5775–7.
- Giesen W. 2000. Flora and Vegetation of Danau Sentarum: Unique Lake and Swamp Forest Ecosystem of West Kalimantan. *Borneo Research Bulletin* 31: 89–122.
- Glew RH, Vanderjagt DJ, Lockett C, Grivetti LE, Smith GC, Pastuszyn A and Millson M. 1997. Amino acid, fatty acid, and mineral composition of 24 indigenous plants of Burkina Faso. *Journal of Food Composition and Analysis* 10: 205–17.
- Goldstein JH, Caldarone G, Duarte TK, Ennaanay D, Hannahs N, Mendoza G, Polasky S, Wolny S and Daily GC. 2012. Integrating ecosystem-service tradeoffs into land-use decisions. *Proceedings of the National Academy of Sciences of the United States of America* 109: 7565–70.
- Gould RK, Ardoin NM, Woodside U, Satterfield T, Hannahs N and Daily GC. 2014. The forest has a story: cultural ecosystem services in Kona, Hawai'i. *Ecology and Society* 19(3): 55.
- GRZ. 2015a. *Zambia's second national biodiversity strategy and action plan 2015-2020 (NBSAP-2)*. Lusaka, Zambia: Government of the Republic of Zambia.
- GRZ. 2015b. *Report of the Auditor General on Sustainable Management of Fish Resources in Natural Waters*. Lusaka, Zambia: Government of the Republic of Zambia.
- GRZ, FAO and Government of Finland. 2016. Biodiversity Report for Integrated Land Use Assessment Phase II (ILUA II). *Technical Report Series*.
- Guo X, Coops NC, Tompalski P, Nielsen SE, Bater CW and John Stadt J. 2017. Regional mapping of vegetation structure for biodiversity monitoring using airborne lidar data. *Ecological Informatics* 38: 50–61.
- Hackman KO. 2014. The state of biodiversity in Ghana: Knowledge gaps and prioritization. *International Journal of Biodiversity and Conservation* 6(9): 681–701.
- Han X, Gill MJ, Hamilton H, Vergara SG and Young BE. 2020. Progress on national biodiversity indicator reporting and prospects for filling indicator gaps in Southeast Asia. *Environmental and Sustainability Indicators* 5.100017.
- Hanks DJ. 2019. Consumption. The action of looking thoughtfully at a consumption and anthropogenic impacts on the environment. MSc thesis, University of Alberta.
- Hansen CP, Pouliot M, Marfo E, Obiri BD and Treue T. 2015. Forests, timber and rural livelihoods: implications for social safeguards in the Ghana-EU voluntary partnership agreement. *Small-scale Forestry* 14: 401–22.
- Hausmann A, Slotow R, Burns JK and Di Minin E. 2016. The ecosystem service of sense of place: benefits for human well-being and biodiversity conservation. *Environmental Conservation* 43: 117–27.
- Herndon CN and Butler RA. 2010. Significance of Biodiversity to Health: Biodiversity and Health. *Biotropica* 42: 558–560.
- Herrera JM, Salgueiro PA, Medinas D, Costa P, Encarnação C and Mira A. 2016. Generalities of vertebrate responses to landscape composition and configuration

- gradients in a highly heterogeneous Mediterranean region. *Journal of Biogeography* 43: 1203–14.
- Hidayat H, Teuling A, Vermeulen B, Taufik M, Kastner K, Geertsema T, Bol D, Hoekman D, Haryani G, Van Lanen H. 2017. Hydrology of inland tropical lowlands: The Kapuas and Mahakam wetlands. *Hydrology and Earth System Sciences* 21(5): 2579–2594.
- Holzner A, Ruppert N, Swat F, Schmidt M, Weiß BM, Villa G, Mansor A, Mohd Sah SA, Engelhardt A, Kühl H, et al. 2019. Macaques can contribute to greener practices in oil palm plantations when used as biological pest control. *Current Biology* 29:R1066–R1067.
- Hooper DU, Adair EC, Cardinale BJ, Byrnes JEK, Hungate BA, Matulich KL, Gonzalez A, Duffy JE, Gamfeldt L, et al. 2012. A global synthesis reveals biodiversity loss as a major driver of ecosystem change. *Nature* 486: 105–8.
- Howe C, Suich H, Vira B and Mace GM. 2014. Creating win-wins from trade-offs? Ecosystem services for human well-being: A meta-analysis of ecosystem service trade-offs and synergies in the real world. *Global Environmental Change* 28: 263–75.
- Hughes FMR, Adams WM, Butchart SHM, Field RH, Peh KS-H and Warrington S. 2016. The challenges of integrating biodiversity and ecosystem services monitoring and evaluation at a landscape-scale wetland restoration project in the UK. *Ecology and Society* 21(3):10.
- Hui D, Deng Q, Tian H and Luo Y. 2015. Climate change and carbon sequestration in forest ecosystems. In Chen W-Y, Suzuki T and Lackner M, eds. *Handbook of Climate Change Mitigation and Adaptation*. New York: Springer. 1–40.
- Husseini R, Baatuuwie B and Issifu H. 2015. Natural forest reserves in the Northern region of Ghana: description and management status. *Research journal's Journal of forestry* 2(6).
- International Tropical Timber Organization (ITTO). 1998. *Borneo Biodiversity Expedition 1997*. Yokohama, Japan.
- International Tropical Timber Organization (ITTO). 2013. *Promoting biodiversity conservation in Betung Kerihun National Park (BKNP) as the trans-boundary ecosystem between Indonesia and the state of Sarawak Malaysia, (Phase III)*. Yokohama, Japan.
- Isbell F, Gonzalez A, Loreau M, Cowles J, Díaz S, Hector A, Mace GM, Wardle DA, O'Connor MI, Duffy JE, et al. 2017. Linking the influence and dependence of people on biodiversity across scales. *Nature* 546: 65–72.
- IUCN 2012. *Livelihoods and Landscapes Strategy. Results and reflections*. Gland, Switzerland: International Union for Conservation of Nature (IUCN). <https://portals.iucn.org/library/sites/library/files/documents/2012-055.pdf>.
- Jasaw GS, Saito O, Gasparatos A, Shoyama K, Bofo YA and Takeuchi K. 2017. Ecosystem services trade-offs from high fuelwood use for traditional shea butter processing in semi-arid Ghana. *Ecosystem services* 27: 127–138.
- Jibreel MB, Mumuni E, Al-Hassan S, Baba NM. 2013. Shea butter and its processing impacts on the environment in the Tamale Metropolis of Ghana. *International Journal of Development and Sustainability* 2(3): 2008–2019.

- Johnson CN, Balmford A, Brook BW, Buettel JC, Galetti M, Guangchun L and Wilmshurst JM. 2017. Biodiversity losses and conservation responses in the Anthropocene. *Science* 356: 270–5.
- Jones HP, Hole DG and Zavaleta ES. 2012. Harnessing nature to help people adapt to climate change. *Nature Climate Change* 2: 504–9.
- Jumbe CBL, Bwalya SM and Husselman M. 2008. Contribution of Dry Forests to Rural Livelihoods and the National Economy in Zambia. In *Managing the Miombo Woodlands of Southern Africa*, Technical Annex No. 1. Washington DC: The World Bank, Sustainable Development Department, Environmental, and Natural Resources Management Unit, Africa Region.
- Keesing F, Belden LK, Daszak P, Dobson A, Harvell CD, Holt RD, Hudson P, Jolles A, Jones KE, Mitchell CE, et al. 2010. Impacts of biodiversity on the emergence and transmission of infectious diseases. *Nature* 468: 647–52.
- Klepper O. 1994. A hydrological model of the Upper Kapuas river and the Kapuas lakes. *Consultancy report for Asian Wetland Bureau/PHPA, for the UK-Indonesia Tropical Forest Management Project*, Sub-project 5 Conservation. Bogor, Indonesia: Asian Wetland Bureau (Wetlands International).
- Kobori H, Dickinson JL, Washitani I, Sakurai R, Amano T, Komatsu N, Kitamura W, Takagawa S, Koyama K, et al. 2016. Citizen science: A new approach to advance ecology, education, and conservation. *Ecological Research* 31: 1–19.
- Kremen C and Merenlender AM. 2018. Landscapes that work for biodiversity and people. *Science* 362:eaau6020.
- Labrière N, Laumonier Y, Locatelli B, Vieilledent G and Comptour M. 2015. Ecosystem services and biodiversity in a rapidly transforming landscape in northern Borneo. *PloS one* 10(10): e0140423.
- Landis DA. 2017. Designing agricultural landscapes for biodiversity-based ecosystem services. *Basic and Applied Ecology* 18: 1–12.
- Lange M, Eisenhauer N, Sierra CA, Bessler H, Engels C, Griffiths RI, Mellado-Vázquez PG, Malik AA, Roy J, Scheu S, et al. 2015. Plant diversity increases soil microbial activity and soil carbon storage. *Nature Communications* 6:6707.
- Laumonier Y, Simamora T, Manurung A, Narulita S, Pribadi U, Simorangkir A, Shantiko B. 2020a. Sentinel landscapes initiative: Stocktake and baseline data analysis for future landscape management and monitoring in West Kalimantan, *FTA Working Paper 5*. Bogor, Indonesia: CIFOR.
- Laumonier Y, Hadi DP, Pribadi UA, Narulita S. 2020b. *Kapuas Hulu Ecological Vegetation Map 1:50000*. Available at: <https://doi.org/10.17528/CIFOR/DATA.00202>. Bogor, Indonesia: CIFOR.
- Lefcheck JS, Byrnes JEK, Isbell F, Gamfeldt L, Griffin JN, Eisenhauer N, Hensel MJS, Hector A, Cardinale BJ and Duffy JE. 2015. Biodiversity enhances ecosystem multifunctionality across trophic levels and habitats. *Nature Communications* 6:6936.
- Leonald L and Rowland D. 2016. Drivers and effects of agrarian change in Kapuas Hulu Regency, West Kalimantan, Indonesia. In: Deakin EL, Kshatriya M, Sunderland TCH,

- eds. *Agrarian Change in Tropical Landscapes*. Bogor, Indonesia: CIFOR. Indonesia <https://doi.org/10.17528/cifor/005867>.
- Liang J, Crowther TW, Picard N, Wiser S, Zhou M, Alberti G, Schulze E-D, McGuire AD, Bozzato F and Pretzsch H. 2016. Positive biodiversity-productivity relationship predominant in global forests. *Science* 354(6309):aaf8957.
- Luque S, Pettorelli N, Vihervaara P and Wegmann M. 2018. Improving biodiversity monitoring using satellite remote sensing to provide solutions towards the 2020 conservation targets. *Methods in Ecology and Evolution* 9: 1784–6.
- Lurimuah S. 2011. The economic and environmental effects of commercial charcoal production in the Upper West Region of Ghana, MSc Thesis, School of Graduate Studies, Kwame Nkrumah University of Science and Technology, Kumasi (<http://hdl.handle.net/123456789/2177>).
- Lyver PO, Timoti P, Gormley AM, Jones CJ, Richardson SJ, Tahī BL and Greenhalgh S. 2017. Key Māori values strengthen the mapping of forest ecosystem services. *Ecosystem Services* 27: 92–102.
- Mabeta J, Mweemba B and Mwitwa J. 2018. Key drivers of biodiversity loss in Zambia. BIOFIN Policy Brief # 3. http://www.biodiversityfinance.net/sites/default/files/content/knowledge_products/BIOFIN%20ZM%20PB%20%233-Divers%20of%20biodiversity%20loss%20in%20Zambia.pdf.
- Macfadyen S, Cunningham SA, Costamagna AC and Schellhorn NA. 2012. Managing ecosystem services and biodiversity conservation in agricultural landscapes: are the solutions the same? *Journal of Applied Ecology* 49: 690–4.
- MacKinnon K, Hatta G, Halim H. and Maigalik A. 1996. *The ecology of Indonesia series*. Volume III—The ecology of Kalimantan, Indonesia, Borneo. Periplus pub. Cambridge: CUP.
- Maller C, Townsend M, Pryor A, Brown P and St Leger L. 2006. Healthy nature healthy people: ‘contact with nature’ as an upstream health promotion intervention for populations. *Health Promotion International* 21: 45–54.
- Markl JS, Schleuning M, Forget PM, Jordano P, Lambert JE, Traveset A, Wright SJ and Böhning-Gaese K. 2012. Meta-analysis of the effects of human disturbance on seed dispersal by animals: Human effects on animal seed dispersal. *Conservation Biology* 26: 1072–81.
- Martin EA, Dainese M, Clough Y, Báldi A, Bommarco R, Gagic V, Garratt MPD, Holzschuh A, Kleijn D, Kovács-Hostyánszki A, et al. 2019. The interplay of landscape composition and configuration: New pathways to manage functional biodiversity and agroecosystem services across Europe. *Ecology Letters* 22: 1083–94.
- Martin EA, Seo B, Park C-R, Reineking B and Steffan-Dewenter I. 2016. Scale-dependent effects of landscape composition and configuration on natural enemy diversity, crop herbivory, and yields. *Ecological Applications* 26: 448–62.
- Martín-López B, Iniesta-Arandia I, García-Llorente M, Palomo I, Casado-Arzuaga I, Amo DGD, Gómez-Baggethun E, Oteros-Rozas E, Palacios-Agundez I, Willaarts B, et al. 2012. Uncovering ecosystem service bundles through social preferences. *PLoS ONE* 7:e38970.

- Matakala PW, Misael K and Jochen S. 2015. Zambia national strategy to reduce emissions from deforestation and forest degradation (REDD+). Harare, Zambia: Forestry Department, Ministry of Lands Natural Resources and Environmental Protection, FAO, UNDP, and UNEP, GRZ.
- McKinley DC, Miller-Rushing AJ, Ballard HL, Bonney R, Brown H, Cook-Patton SC, Evans DM, French RA, Parrish JK, Phillips TB, et al. 2017. Citizen science can improve conservation science, natural resource management, and environmental protection. The role of citizen science in biological conservation. *Biological Conservation* 208: 15–28.
- Mcowen CJ, Ivory S, Dixon MJR, Regan EC, Obrecht A, Tittensor DP, Teller A and Chenery AM. 2016. Sufficiency and suitability of global biodiversity indicators for monitoring progress to 2020 targets: Sufficiency and suitability of biodiversity indicators. *Conservation Letters* 9: 489–94.
- Mensah R, Effah AK, Attua EM, Chimsah FA, Boakye-Danquah J, Sackey I .2016. Biodiversity of woody species and their utilization in a Savannah ecological zone of Northern Ghana. *Journal of Biodiversity and Environmental Sciences (JBES)* 8(3): 22-45.
- Mihoub J-B, Henle K, Titeux N, Brotons L, Brummitt NA and Schmeller DS. 2017. Setting temporal baselines for biodiversity: The limits of available monitoring data for capturing the full impact of anthropogenic pressures. *Scientific Reports* 7: 41591.
- Miles L, Newton AC, DeFries RS, Ravilious C, May I, Blyth S, Kapos V and Gordon JE. 2006. A global overview of the conservation status of tropical dry forests. *Journal of biogeography* 33(3): 491-505.
- Montoya D, Gaba S, de Mazancourt C, Bretagnolle V and Loreau M. 2020. Reconciling biodiversity conservation, food production and farmers' demand in agricultural landscapes. *Ecological Modelling* 416: 108889.
- Mori AS, Lertzman KP and Gustafsson L. 2017. Biodiversity and ecosystem services in forest ecosystems: A research agenda for applied forest ecology. *Journal of Applied Ecology* 54: 12–27.
- Mulenga B, Richardson R and Tembo G. 2012. Non-Timber Forest Products and Rural Poverty Alleviation in Zambia. Working Paper No. 62. Lusaka, Zambia: Indaba Agricultural Policy Research Institute.
- Naro E, Mero EL, Naro E, Kapfo K, Wezah K, Thopi K, Rhakho K, Akami L, Thopi L, Chirhah M, et al. 2015. Project hunt: An assessment of wildlife hunting practices by local community in Chizami, Nagaland, India. *Journal of Threatened Taxa* 7: 7729–43.
- Nelson E, Mendoza G, Regetz J, Polasky S, Tallis H, Cameron DR, Chan KM, Daily GC, Goldstein J, Kareiva PM, et al. 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. *Frontiers in Ecology and the Environment* 7: 4–11.
- Newbold T, Hudson LN, Hill SLL, Contu S, Lysenko I, Senior RA, Börger L, Bennett DJ, Choimes A, Collen B, et al. 2015. Global effects of land use on local terrestrial biodiversity. *Nature* 520: 45–50.
- Newton P, Kinzer AT, Miller DC, Oldekop JA and Agrawal A. 2020. The number and spatial distribution of forest-proximate people globally. *One Earth* 3: 363–70.

- Oehri J, Schmid B, Schaepman-Strub G and Niklaus PA. 2017. Biodiversity promotes primary productivity and growing season lengthening at the landscape scale. *Proceedings of the National Academy of Sciences of the United States of America* 114: 10160–5.
- O'Farrell PJ and Anderson PM. 2010. Sustainable multifunctional landscapes: A review to implementation. *Current Opinion in Environmental Sustainability* 2: 59–65.
- Oliver TH, Heard MS, Isaac NJB, Roy DB, Procter D, Eigenbrod F, Freckleton R, Hector A, Orme CDL, Petchey OL, et al. 2015. Biodiversity and resilience of ecosystem functions. *Trends in Ecology & Evolution* 30: 673–84.
- Olivero J, Fa JE, Real R, Márquez AL, Farfán MA, Vargas JM, Gaveau D, Salim MA, Park D and Suter J. 2017. Recent loss of closed forests is associated with Ebola virus disease outbreaks. *Scientific Reports* 7: 1–9.
- Ollerton J, Winfree R and Tarrant S. 2011. How many flowering plants are pollinated by animals? *Oikos* 120: 321–6.
- Overton J, Davis S, Nguluka L, Nsende E, Sompa B, Simukonda C and Lindsey P. 2017. The Illegal bushmeat trade in the greater Kafue Ecosystem, Zambia: Drivers Impacts and Solutions. FAO <http://www.fao.org/3/a-bc610e.pdf> and.
- Owusu-Ansah N. 2018. Assessing How Collaborative Resource Management Impacts Victims Perspectives on Wildlife Crop Raids. *Journal of Natural Resources and Development* 08: 115–124.
- Paumgarten F and Shackleton CM. 2009. Wealth differentiation in household use and trade in non-timber forest products in South Africa. *Ecological Economics* 68: 2950–9.
- Peraturan Daerah (PERDA) Kabupaten Kapuas Hulu 2014. (Regional Regulation (PERDA) on the Kapuas Hulu District Spatial Plan for 2014 – 2034). *Kapuas Hulu District Spatial Plan 2014-2034*. Bupati Kapuas Hulu, Putussibau, Indonesia. <https://peraturan.bpk.go.id/Home/Details/51239/perda-kab-kapuas-hulu-no-1-tahun-2014>.
- Potts SG, Imperatriz-Fonseca V, Ngo HT, Aizen MA, Biesmeijer JC, Breeze TD, Dicks LV, Garibaldi LA, Hill R, Settele J, et al. 2016. Safeguarding pollinators and their values to human well-being. *Nature* 540: 220–9.
- Pouliot M and Treue T. 2013. Rural people's reliance on forests and the non-forest environment in West Africa: Evidence from Ghana and Burkina Faso. *World Development* 43: 180–93.
- Powell B, Thilsted SH, Ickowitz A, Termote C, Sunderland T and Herforth A. 2015. Improving diets with wild and cultivated biodiversity from across the landscape. *Food Security* 7: 535–54.
- Raes N. 2009. Borneo: A quantitative analysis of botanical richness, endemism and floristic regions based on herbarium records. PhD thesis National Herbarium Nederland, Leiden University.
- Rasmussen LV, Watkins C and Agrawal A. 2017. Forest contributions to livelihoods in changing agriculture-forest landscapes. *Forest Policy and Economics* 84: 1–8.
- Raudsepp-Hearne C, Peterson GD and Bennett EM. 2010. Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. *Proceedings of the National Academy of Sciences of the United States of America* 107: 5242–7.

- Reed J, Ickowitz A, Chervier C, Djoudi H, Moombe K, Ros-Tonen M, Yanou M, Yuliani L and Sunderland T. 2020. Integrated landscape approaches in the tropics: A brief stock-take. *Land Use Policy* 99: 104822.
- Reed J, van Vianen J, Barlow J and Sunderland T. 2017. Have integrated landscape approaches reconciled societal and environmental issues in the tropics? *Land Use Policy* 63: 481–92.
- Richardson RB. 2010. Ecosystem services and food security: Economic perspectives on environmental sustainability. *Sustainability* 2: 3520–48.
- Rocchini D, Luque S, Pettorelli N, Bastin L, Doktor D, Faedi N, Feilhauer H, Féret J-B, Foody GM, Gavish Y, et al. 2018. Measuring β -diversity by remote sensing: A challenge for biodiversity monitoring. *Methods in Ecology and Evolution* 9: 1787–98.
- Rochette A-J, Akpona JDT, Akpona HA, Akouehou GS, Kwezi BM, Djagoun CAMS, Habonimana B, Idohou R, Legba IS, Nzigidahera B, et al. 2019. Developing policy-relevant biodiversity indicators: Lessons learnt from case studies in Africa. *Environmental Research Letters* 14: 035002.
- Runting RK, Bryan BA, Dee LE, Maseyk FJ, Mandle L, Hamel P, Wilson KA, Yetka K, Possingham HP and Rhodes JR. 2017. Incorporating climate change into ecosystem service assessments and decisions: A review. *Global Change Biology* 23: 28–41.
- Russell R, Guerry AD, Balvanera P, Gould RK, Basurto X, Chan KMA, Klain S, Levine J and Tam J. 2013. Humans and nature: How knowing and experiencing nature affect well-being. *Annual Review of Environment and Resources* 38: 473–502.
- Sakschewski B, von Bloh W, Boit A, Poorter L, Peña-Claros M, Heinke J, Joshi J and Thonicke K. 2016. Resilience of Amazon forests emerges from plant trait diversity. *Nature Climate Change* 6: 1032–6.
- Sandifer PA, Sutton-Grier AE and Ward BP. 2015. Exploring connections among nature, biodiversity, ecosystem services, and human health and well-being: Opportunities to enhance health and biodiversity conservation. *Ecosystem Services* 12: 1–15.
- Sardeshpande M and Shackleton C. 2019. Wild edible fruits: A systematic review of an under-researched multifunctional NTFP (non-timber forest product). *Forests* 10: 467.
- Sayer J, Margules C, Bohnet I, Boedhihartono A, Pierce R, Dale A and Andrews K. 2015. The role of citizen science in landscape and seascape approaches to integrating conservation and development. *Land* 4: 1200–12.
- Sayer J, Sunderland T, Ghazoul J, Pfund J-L, Sheil D, Meijaard E, Venter M, Boedhihartono AK, Day M, Garcia C, et al. 2013. Ten principles for a landscape approach to reconciling agriculture, conservation, and other competing land uses. *Proceedings of the National Academy of Sciences of the United States of America* 110: 8349–56.
- Schleicher J, Zaehring JG, Fastré C, Vira B, Visconti P and Sandbrook C. 2019. Protecting half of the planet could directly affect over one billion people. *Nature Sustainability* 2: 1094–6.
- Shantiko B, Fripp E, Taufiqoh T, Heri T and Laumonier Y. 2013. *Socio-economic considerations for land-use planning; The case of Kapuas Hulu, West Kalimantan*. Working Paper 120. Bogor, Indonesia: CIFOR.

- Soedjito H. 1999. *Flora dan fauna Taman Nasional Betung Kerihun, Kalimantan Barat (Flora and Fauna of Bentung Kerihun National Park, West Kalimantan)*. Jakarta: WWF Indonesia - PHPA - LIPI - ITTO. iii-88. ISBN 979-95102-2-8.
- Soliveres S, van der Plas F, Manning P, Prati D, Gossner MM, Renner SC, Alt F, Arndt H, Baumgartner V, Binkenstein J, et al. 2016. Biodiversity at multiple trophic levels is needed for ecosystem multifunctionality. *Nature* 536: 456–9.
- Strasser B, Baudry J, Mahr D, Sanchez G. and Tancoigne É. 2019. “Citizen science”? Rethinking science and public participation. *Science & Technology Studies* 32: 52–76.
- Sunderland TCH. 2011. Food security: Why is biodiversity important? *International Forestry Review* 13: 265–74.
- Swamy L, Drazen E, Johnson WR and Bukoski JJ. 2018. The future of tropical forests under the United Nations Sustainable Development Goals. *Journal of Sustainable Forestry* 37: 221–56.
- Swayne DA, Yang W, Voinov AA, Rizzoli A and Filatova T, eds. 2010. Multi-Scale Modelling of Ecosystem Services—an Iterative Approach. International Congress on Environmental Modelling and Software Modelling for Environment’s Sake. International Environmental Modelling and Software Society (iEMSS) Fifth Biennial Meeting. July 5 - 8 2010. Ottawa. Canada. <http://www.iemss.org/iemss2010/index.php?n=Main.Proceedings>.
- Synes NW, Brown C, Watts K, White SM, Gilbert MA and Travis JMJ. 2016. Emerging opportunities for landscape ecological modelling. *Current Landscape Ecology Reports* 1: 146–67.
- Treanor NB. 2015. *China’s Hongmu Consumption Boom: Analysis of the Chinese Rosewood Trade and Links to Illegal Activity in Tropical Forested Countries*. Forest Trends Report Series, Forest Trade and Finance. Washington: Forest Trends.
- Tully K and Ryals R. 2017. Nutrient cycling in agroecosystems: Balancing food and environmental objectives. *Agroecology and Sustainable Food Systems* 41: 761–98.
- Tzilivakis J, Warner DJ, Green A, Lewis KA and Angileri V. 2016. An indicator framework to help maximise potential benefits for ecosystem services and biodiversity from ecological focus areas. *Ecological Indicators* 69: 859–72.
- Valerio F, Basile M, Balestrieri R, Posillico M, Di Donato S, Altea, T and Matteucci G. 2016. The reliability of a composite biodiversity indicator in predicting bird species richness at different spatial scales. *Ecological Indicators* 71: 627–35.
- van der Geest K, de Sherbinin A, Kienberger S, Zommers Z, Sitati A, Roberts E and James R. 2019. The impacts of climate change on ecosystem services and resulting losses and damages to people and society. In Mechler R, Bouwer LM, Schinko T, Surminski S and Linnerooth-Bayer J, eds. *Loss and Damage from Climate Change: Concepts, Methods and Policy Options*. Cham: Springer International Publishing. 221–36.
- van der Heijden MG, de Bruin S, Luckerhoff L, van Logtestijn RS and Schlaeppi K. 2016. A widespread plant-fungal-bacterial symbiosis promotes plant biodiversity, plant nutrition and seedling recruitment. *The ISME Journal* 10: 389–99.
- van der Plas F, Ratcliffe S, Ruiz-Benito P, Scherer-Lorenzen M, Verheyen K, Wirth C, Zavala MA, Ampoorter E, Baeten L, Barbaro L, et al. 2018. Continental mapping

- of forest ecosystem functions reveals a high but unrealised potential for forest multifunctionality. *Ecology Letters* 21: 31–42.
- Veres A, Petit S, Conord C and Lavigne C. 2013. Does landscape composition affect pest abundance and their control by natural enemies? A review. *Agriculture, Ecosystems & Environment* 166: 110–7.
- Verhagen W, van der Zanden EH, Strauch M, van Teeffelen AJA and Verburg PH. 2018. Optimizing the allocation of agri-environment measures to navigate the trade-offs between ecosystem services, biodiversity and agricultural production. *Environmental Science & Policy* 84: 186–96.
- Vihervaara P, Auvinen A-P, Mononen L, Törmä M, Ahlroth P, Anttila S, Böttcher K, Forsius M, Heino J, Heliölä J, et al. 2017. How essential biodiversity variables and remote sensing can help national biodiversity monitoring. *Global Ecology and Conservation* 10: 43–59.
- Vinceti B, Ickowitz A, Powell B, Kehlenbeck K, Termote C and Cogill B. 2013. *The contribution of forests to sustainable diets*. Page 30. International Conference on Forests for Food Security and Nutrition. Rome. 13–15 May 2013.
- Vira B, Agarwal B, Jamnadass R, Kleinschmit D, McMullin S, Mansourian S, Neufeldt H, Parrotta JA, Sunderland T and Wildburger C. 2015. 1. Forests, trees and landscapes for food security and nutrition. In Vira B, Wildburger C and Mansourian S, eds. *Forests and Food: Addressing Hunger and Nutrition Across Sustainable Landscapes*. Open Book Publishers. Cambridge. United Kingdom. 9–26.
- Voigt CC and Kingston T, eds. 2016. *Bats in the Anthropocene: Conservation of Bats in a Changing World*. Cham: Springer International Publishing.
- Weihreter E. 2014. Traditional knowledge, perceptions and forest conditions in a Dayak Mentebah community, West Kalimantan, Indonesia. Working Papers Series n° 156. Bogor, Indonesia: Center for International Forestry Research (CIFOR).
- WHO. 2002. World Health Organization Traditional medicine strategy 2002–2005. http://whqlibdoc.who.int/hq/2002/WHO_EDM_TRM_2002.1.pdf.
- Widianingsih N, Theilade I and Pouliot M. 2016. Contribution of forest restoration to rural livelihoods and household income in Indonesia. *Sustainability* 8: 835.
- Widmann P, Tjiu A, Putera MH, Syahirsyah and Wulffraat S. 2012. Connecting diversity: People and nature of Labian-Leboyan corridor in the Indonesian Heart of Borneo. Jakarta: WWF Indonesia.
- Witter R and Satterfield T. 2019. The ebb and flow of indigenous rights recognitions in conservation policy: Indigenous rights recognitions in conservation policy. *Development and Change* 50: 1083–1108.
- World Bank 2002. Project appraisal document on a proposal grant from the Global Environmental Facility Trust Fund in the amount of SDR 6.0 million to the Republic of Ghana for a northern savanna biodiversity conservation project. Report No: 21 847-GH. <http://documents1.worldbank.org/curated/en/566881468774676876/pdf/multiopage.pdf>.
- WorldClim. 2018. Global Climate Data. Available at: <https://worldclim.org/>.

- Wulffraat S, Greenwood C, Faisal KF, Sucipto D, Chan H, Beukeboom H, Soulisa N and Kinasih A. 2017. *The Environmental Status of Borneo 2016 Report*. Jakarta, Indonesia: Heart of Borneo Programme.
- Wunder S, Börner J, Shively G and Wyman M. 2014. Safety nets, gap filling and forests: A global-comparative perspective. *World Development* 64:S29–S42.
- Yang G, Wagg C, Veresoglou SD, Hempel S and Rillig MC. 2018. How soil biota drive ecosystem stability. *Trends in Plant Science* 23: 1057–67.
- Yuliani EL, de Jong EB, Knippenberg L, Bakara DO, Salim MA and Sunderland T. 2018. Keeping the land: Indigenous communities' struggle over land use and sustainable forest management in Kalimantan, Indonesia. *Ecology & Society* 23(4).
- Yuliani EL, Indriatmoko Y, Salim MA, Farid IZ, Muhajir M, Prasetyo LB, Heri V. 2010. Biofuel policies and their impacts on local people and biodiversity: A case study in Danau Sentarum. *Borneo Research Bulletin* 41: 109–144.
- Zanzanaini C, Trần BT, Singh C, Hart A, Milder J and DeClerck F. 2017. Integrated landscape initiatives for agriculture, livelihoods and ecosystem conservation: An assessment of experiences from South and Southeast Asia. *Landscape and Urban Planning* 165: 11–21.